Di-Electron Widths of $\Upsilon(1S)$, $\Upsilon(2S)$, and $\Upsilon(3S)$ as a Test of Lattice QCD

Jim Pivarski

CLEO Collaboration

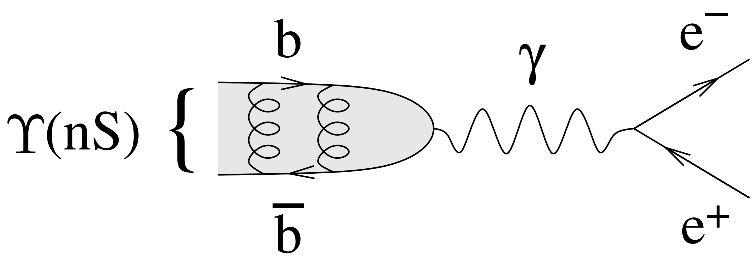
Definition and Motivation

Di-electron width $\Gamma_{ee} = \mathcal{B}_{ee}\Gamma$

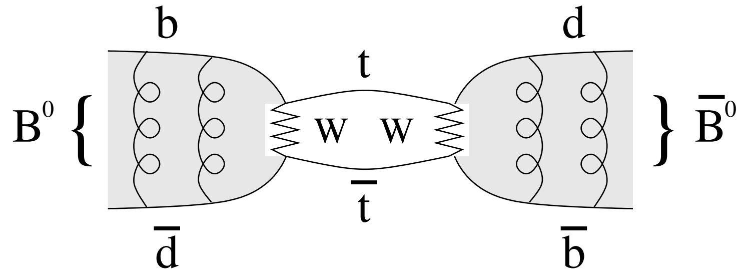
Goal: precisely measure Γ_{ee} of $\Upsilon(1S)$, $\Upsilon(2S)$, and $\Upsilon(3S)$

Why?

Γ_{ee}



$f_B{}^2$



Treated similarly in Lattice QCD

Lattice QCD calculations of Γ_{ee} and f_B are both in progress

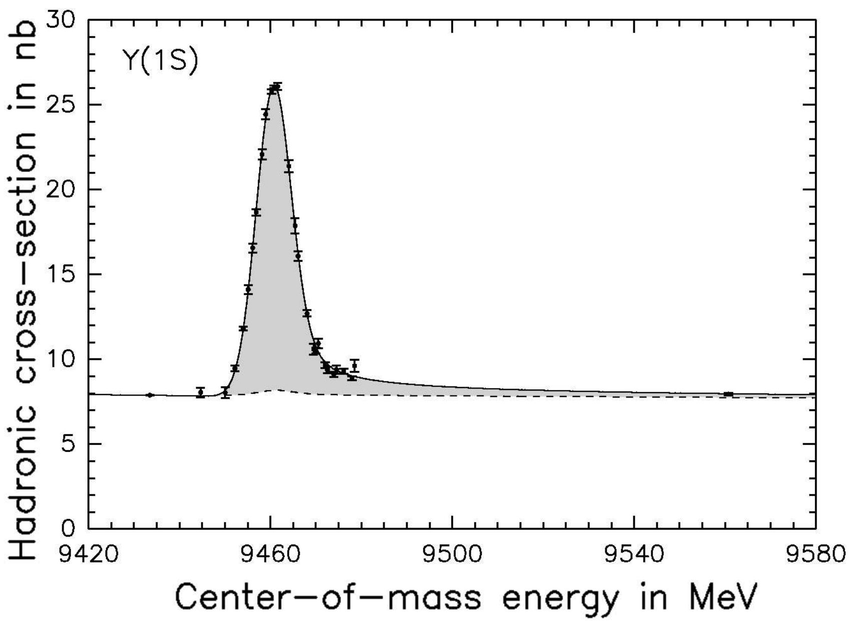
Γ_{ee} gives us three high-precision tests of Lattice QCD in a decay related to B mixing

Experimental Technique

Use the time-reversed process: production cross-section of Υ from e^+e^-

$$\Gamma_{ee} = \frac{M_{\Upsilon}{}^2}{6\pi^2} \int \sigma(e^+e^- \to \Upsilon)\, dE$$

Resonances scanned by Cornell Electron Storage Ring (Nov 2001 – Aug 2002)



Data collected by CLEO-III detector:

	scan	off-resonance
$\Upsilon(1S)$	0.10 fb^{-1}	0.18 fb^{-1}
$\Upsilon(2S)$	0.06 fb^{-1}	0.44 fb^{-1}
$\Upsilon(3S)$	0.10 fb^{-1}	0.16 fb^{-1}

50 times Novosibirsk 1996

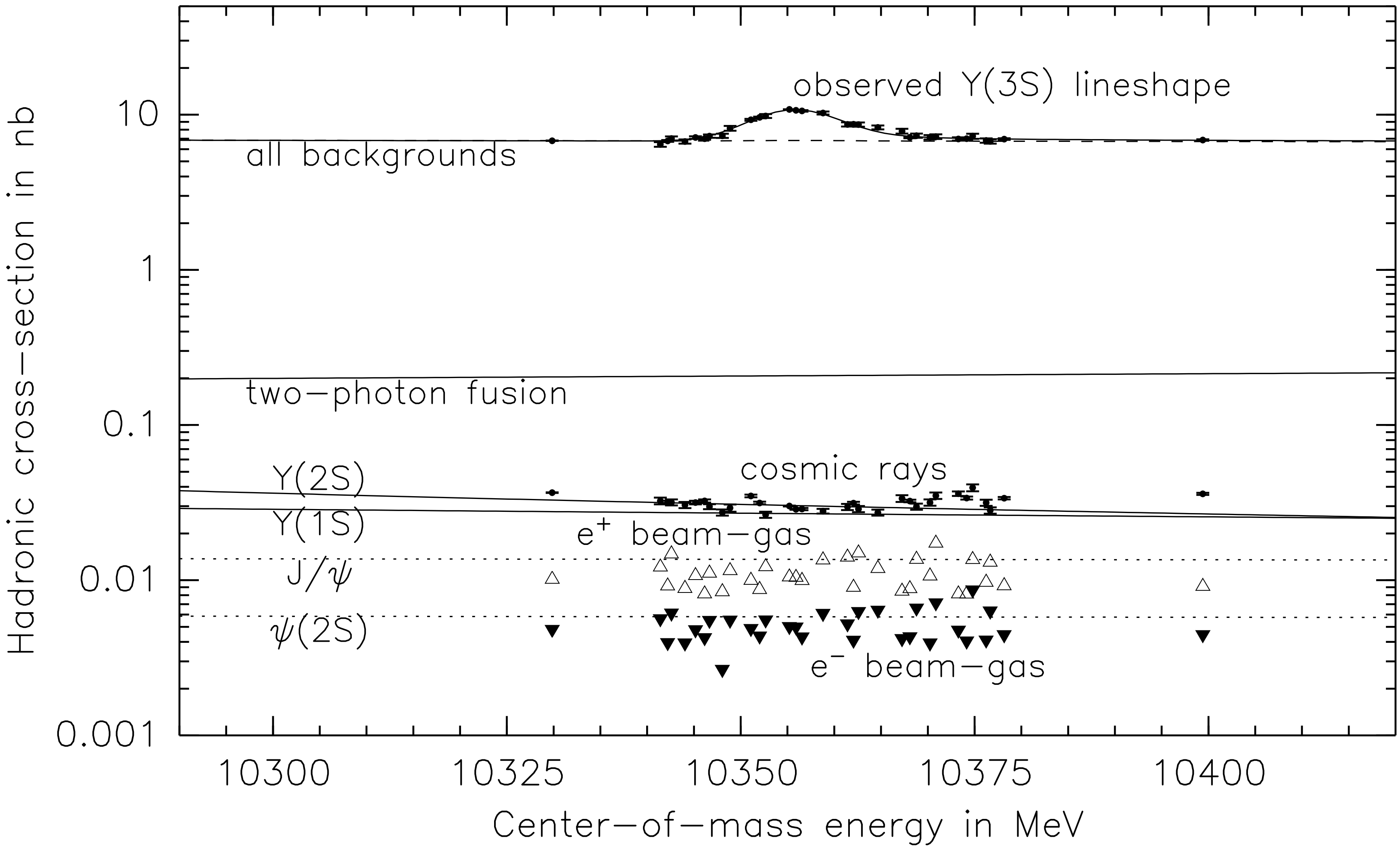
All but a well-measured fraction of Υ decays are hadronic

Select hadronic final states inclusively

Hadronic Backgrounds

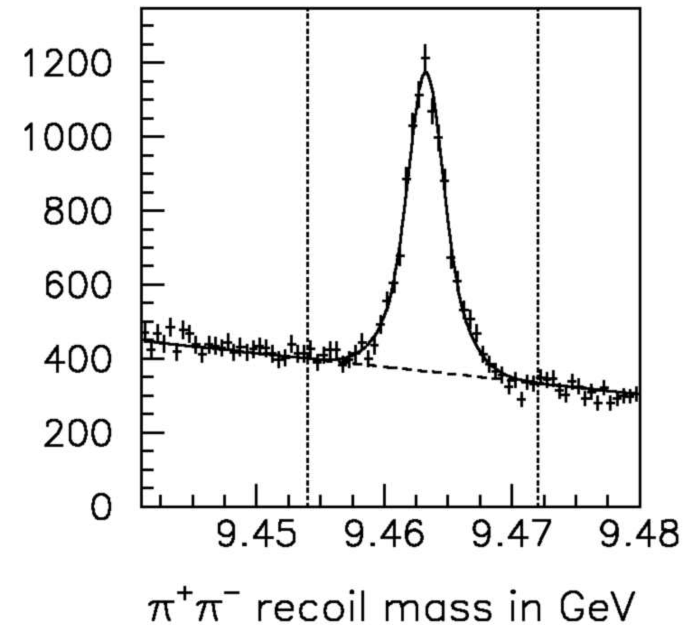
Most are effectively subtracted by including a $1/s$ term in the fit

The rest are very small corrections



Hadronic Efficiency

Model-independent, data-based method for measuring hadronic efficiency:



Select $\Upsilon(2S) \to \pi^+\pi^- \ \Upsilon(1S)$
based on $\pi^+\pi^-$ only (1.3 fb^{-1})

Set of recoiling $\Upsilon(1S)$ events includes all decays,
even undetectable modes

#pass/#total $= \epsilon_{1S} =$ (97.8 $\pm$ 0.5)%

$\Upsilon(2S)$ and $\Upsilon(3S)$ inherit this efficiency with (largest) correction for

$$\Upsilon' \to X\Upsilon \to X\ell^+\ell^- \qquad (\ell \text{ is } e \text{ or } \mu)$$

$X\ell^+\ell^-$ branching fractions measured in data (1.58 $\pm$ 0.15)% and (1.34 $\pm$ 0.15)%

$\epsilon_{2S} =$ (95.8 $\pm$ 0.6)% and $\epsilon_{3S} =$ (96.0 $\pm$ 0.6)%

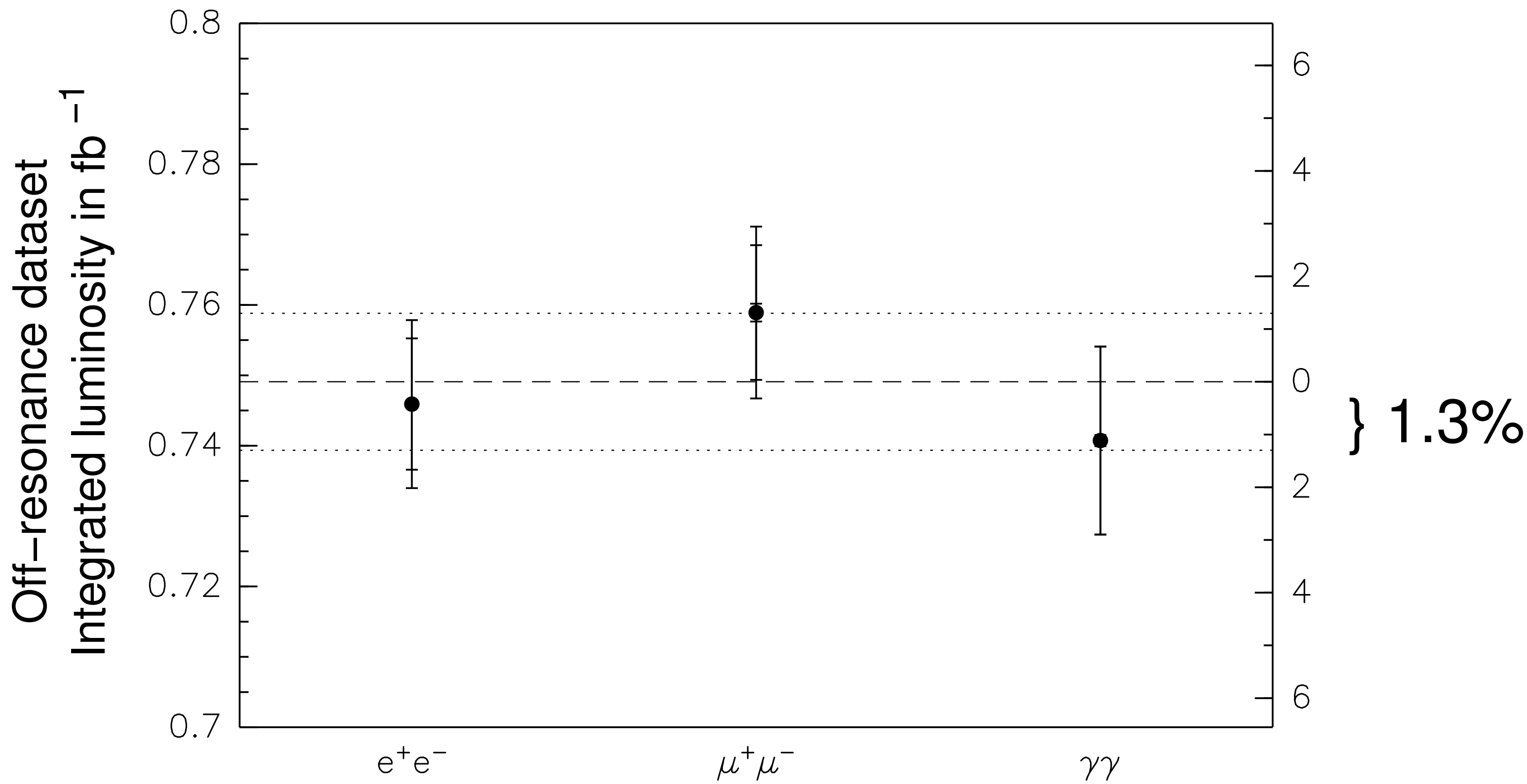
Integrated Luminosity

We need integrated luminosity for every cross-section measurement:

$$\boldsymbol{\sigma_i} = (\#\ \text{hadrons})_i/(\text{integrated luminosity})_i$$

Count $e^+e^- \to \gamma\gamma$ events at each energy point ($\Upsilon \not\to \gamma\gamma$)

Normalize to physical units (nb^{-1})



Beam Energy Measurement

Obtain $\boldsymbol{E_{beam}}$ from dipole $\vec{\boldsymbol{B}}$ measurement

(sensitive to position of probe)

Collect scan data in short, independent trials

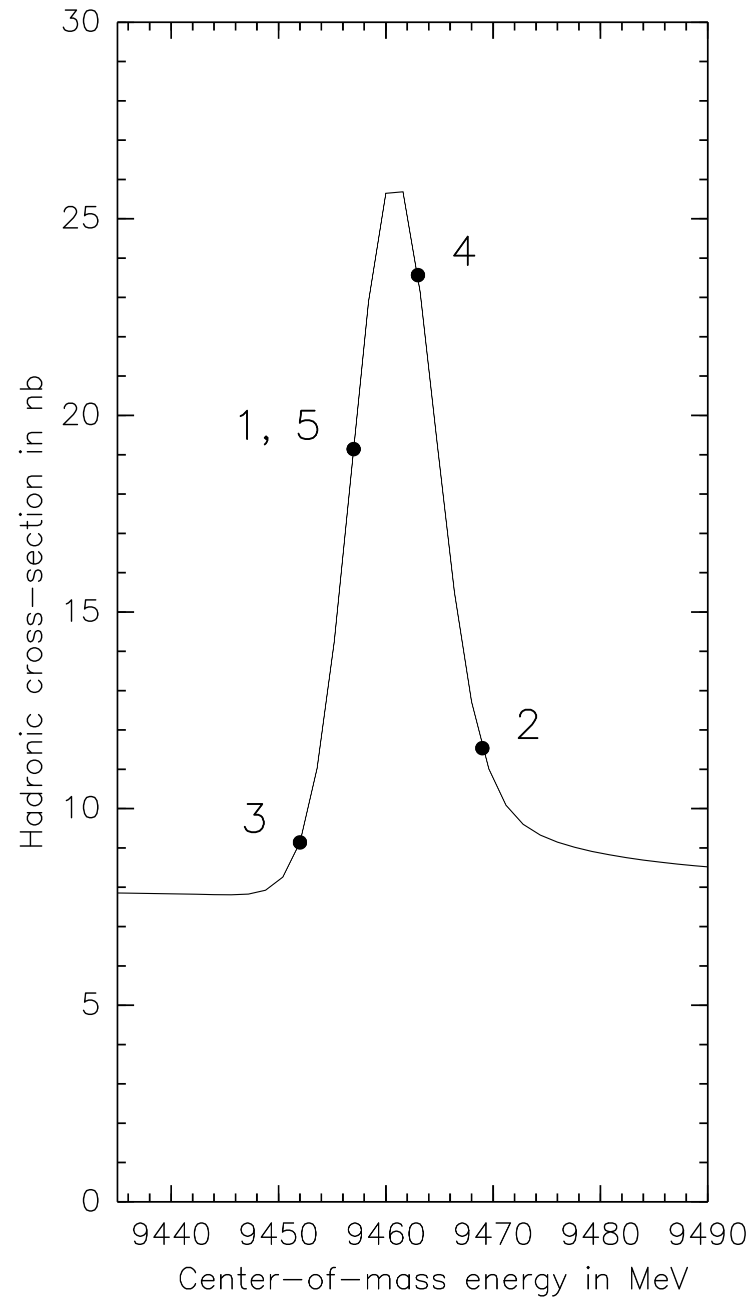
$\longrightarrow$ $\boldsymbol{E_{beam}}$ is reproducible to $\sim$ 0.5 MeV between mini-scans

Alternate scan order above and below peak

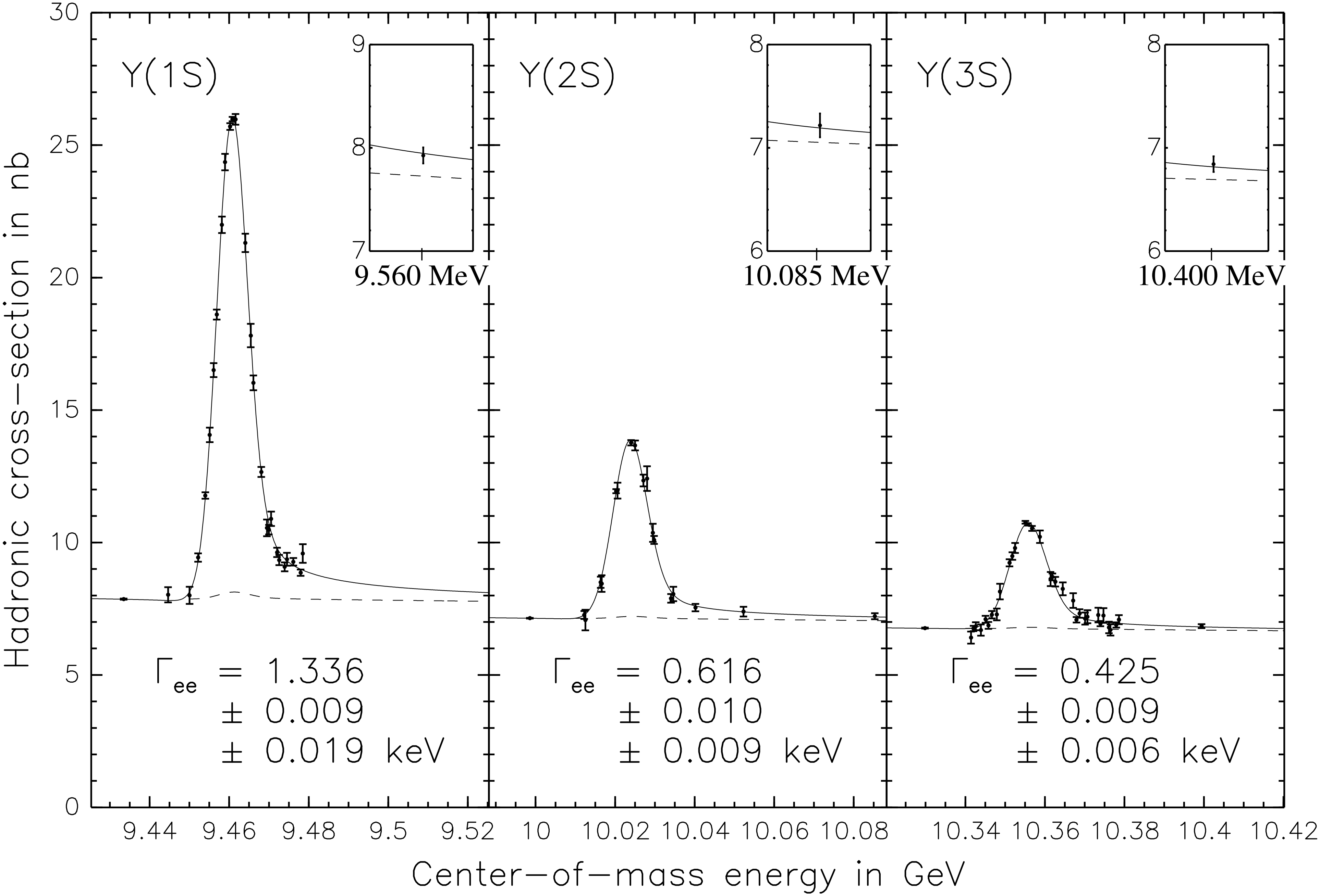
Repeat point of highest slope

$\longrightarrow$ $\boldsymbol{E_{beam}}$ is reproducible to $\lesssim$ 0.07 MeV during a mini-scan

$\longrightarrow$ 0.2% uncertainty in $\boldsymbol{\Gamma_{ee}}$



Fit Results



Υ(1S)
Υ(2S)
Υ(3S)
9.560 MeV
10.085 MeV
10.400 MeV
Γee = 1.336
± 0.009
± 0.019 keV
Γee = 0.616
± 0.010
± 0.009 keV
Γee = 0.425
± 0.009
± 0.006 keV
Hadronic cross-section in nb
Center-of-mass energy in GeV

Summary of Uncertainties

Preliminary Results

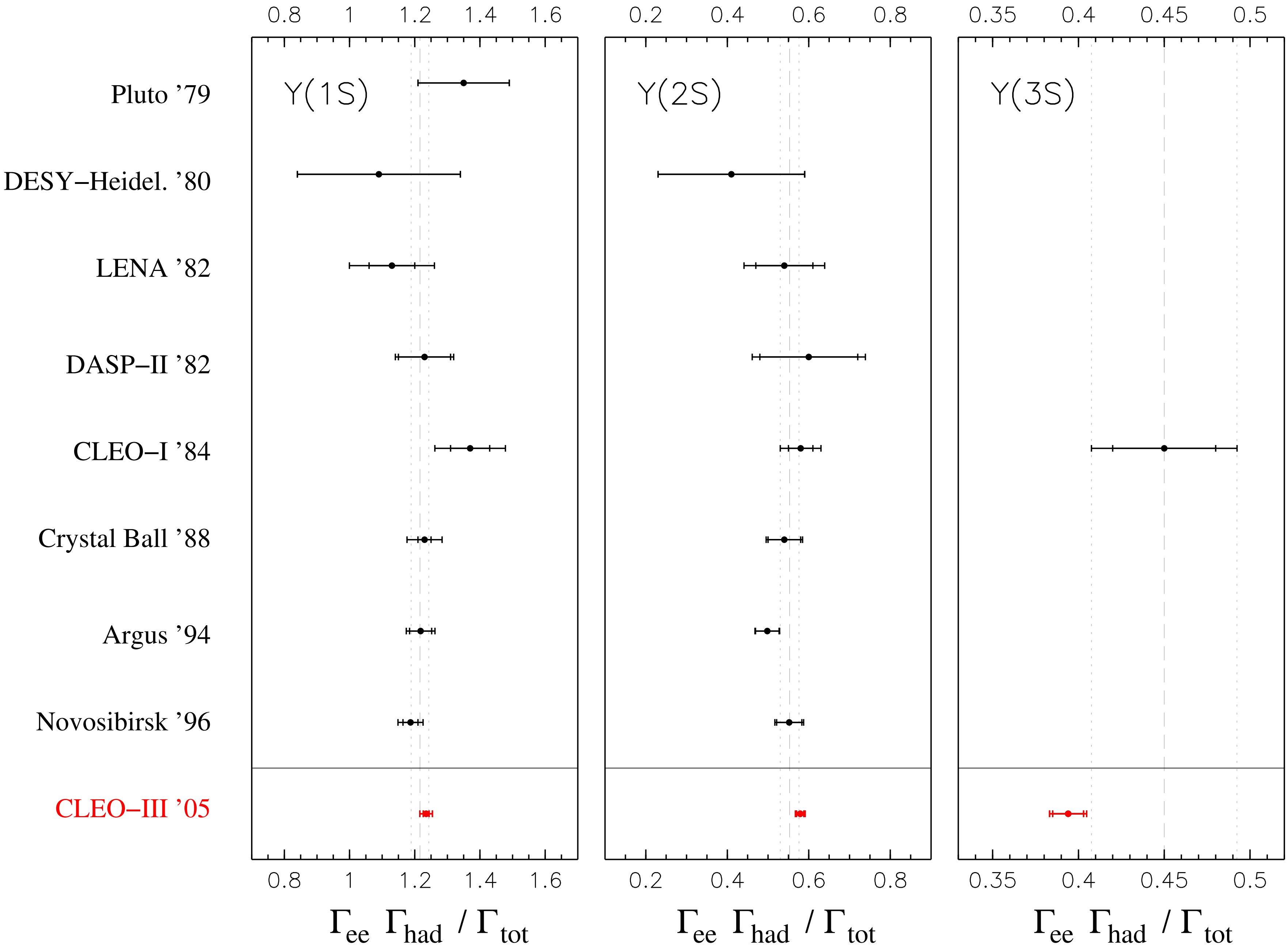
Contribution to Γ_{ee}	$\Upsilon(1S)$	$\Upsilon(2S)$	$\Upsilon(3S)$
Statistical*	0.7%	1.6%	2.2%
Correct for leptonic modes	0.2%	0.2%	0.3%
Hadronic efficiency	0.5%	0.6%	0.7%
Luminosity calibration	$\longleftarrow$	1.3%	$\longrightarrow$
Cross-section stability	0.1%	0.1%	0.1%
Beam-energy stability	0.2%	0.2%	0.2%
Shape of the fit function	0.05%	0.06%	0.05%
Total	1.6%	2.2%	2.7%

* Statistical uncertainty is dominated by $\gamma\gamma$ counting

Preliminary Results

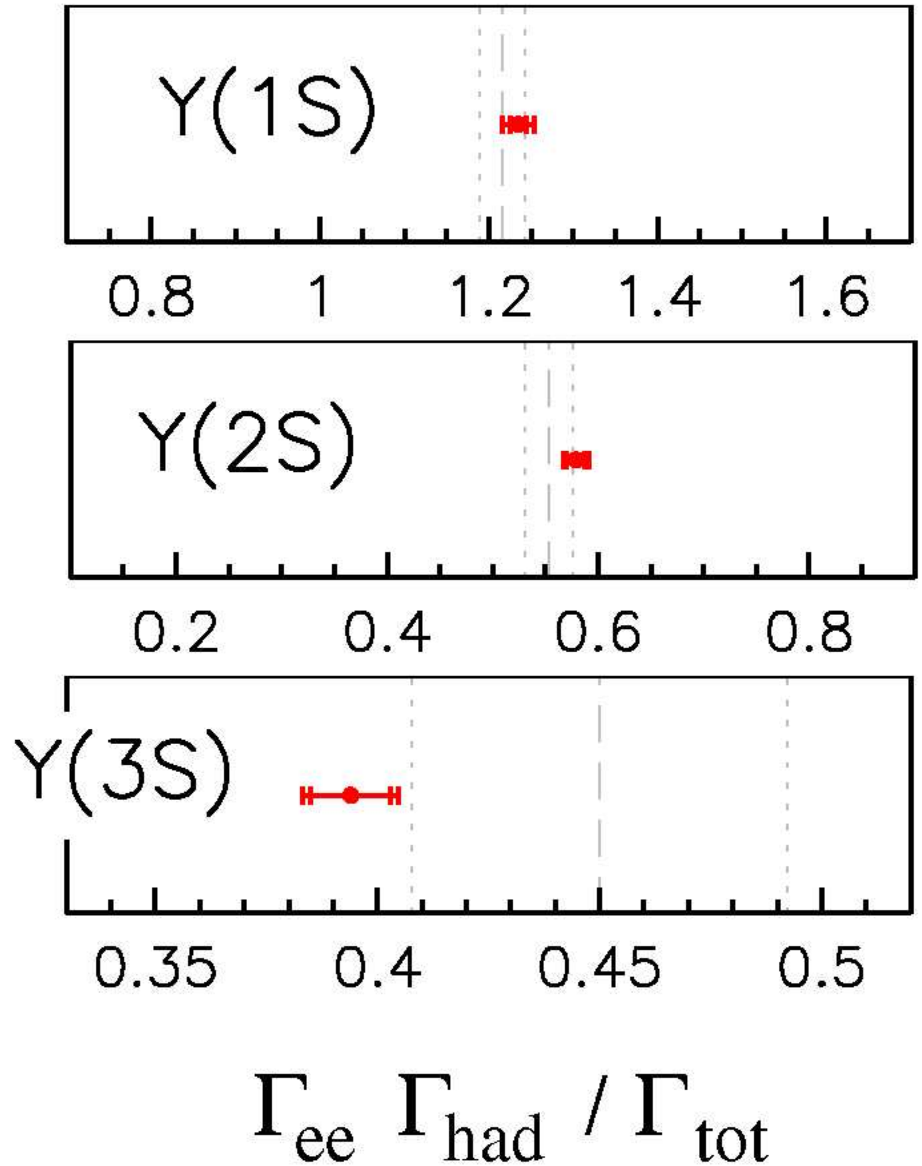
Quantity	Value	Uncertainty
$\Gamma_{ee}(1S)$	$1.336 \pm 0.009 \pm 0.019$ keV	1.6%
$\Gamma_{ee}(2S)$	$0.616 \pm 0.010 \pm 0.009$ keV	2.2%
$\Gamma_{ee}(3S)$	$0.425 \pm 0.009 \pm 0.006$ keV	2.7%
$\Gamma_{ee}(2S)/\Gamma_{ee}(1S)$	$0.461 \pm 0.008 \pm 0.003$	1.8%
$\Gamma_{ee}(3S)/\Gamma_{ee}(1S)$	$0.318 \pm 0.007 \pm 0.002$	2.4%
$\Gamma_{ee}(3S)/\Gamma_{ee}(2S)$	$0.690 \pm 0.019 \pm 0.006$	2.8%

Preliminary Results (keV)



Preliminary Results (keV)

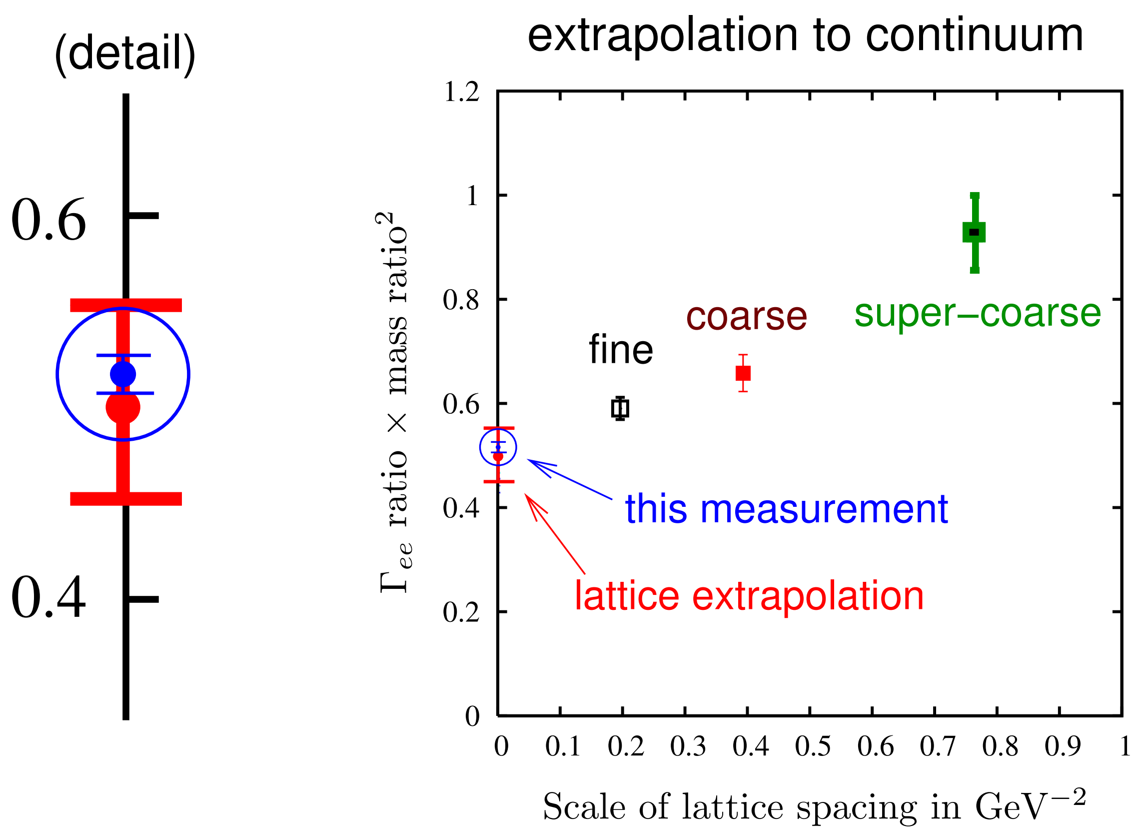
CLEO–III '05



Comparison with Theory

Lattice calculation is still in progress, but ratio of $\boldsymbol{\Gamma_{ee}(2S)/\Gamma_{ee}(1S)}$ may be compared

Partial result is very sensitive to lattice spacing `hep-lat/0507013`



Consistent, but with 10% uncertainty (due to extrapolation)

Final lattice precision will be few percent in *ratios*

Conclusions

Very careful 1.5–3% measurement of Γ_{ee} and Γ_{ee} ratios

Final result will determine luminosity from e^+e^-, rather than $\gamma\gamma$

Tight constraint on Lattice QCD, also a useful input for potential model fits

With new $\mathcal{B}_{\mu\mu}$ from `PRL 94, 012001` (2005),

$\Gamma(1S)$	53.7 $\pm$ 1.7 keV	3.2%	(0.3 σ above PDG)
$\Gamma(2S)$	30.3 $\pm$ 1.4 keV	4.5%	(2.1 σ below PDG)
$\Gamma(3S)$	17.8 $\pm$ 1.0 keV	5.8%	(2.4 σ below PDG)